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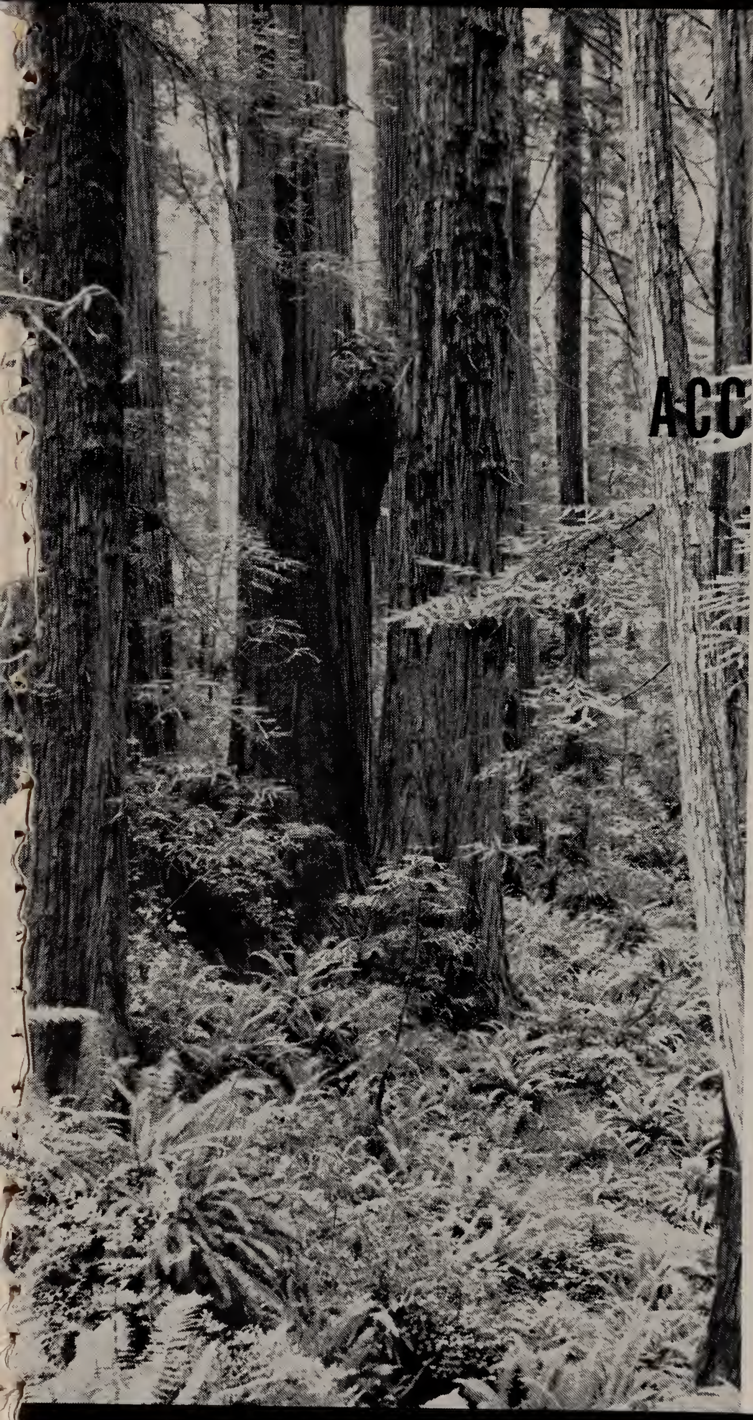

ACCELERATING THE DRYING OF REDWOOD LUMBER

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

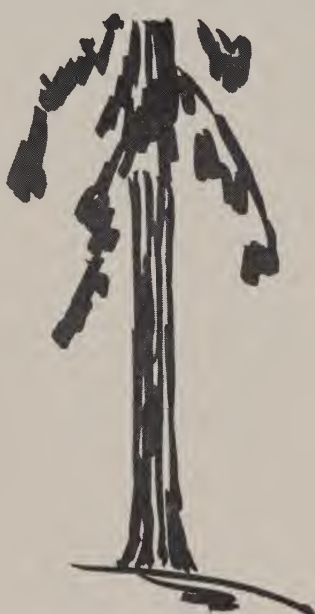
BULLETIN 803

Annually, some 980 million board feet of California's redwood sawtimber are converted into lumber (USDA Forest Service, 1958). The largest portion of this product must be dried to 8–10 per cent moisture content. The long drying time required, the longest for any commercial softwood species, represents a major problem in the manufacturing process. Millions of board feet of lumber are tied up in air drying yards, representing a large capital investment.

Speeding up the drying process would make the lumber available for the market much sooner after sawing than is now possible and reduce the amount of lumber that needs to be stored.

This bulletin

- briefly reviews the literature of redwood drying,
- presents results on experimental kiln drying of 4/4" heavy segregation lumber, and
- discusses various aspects of the acceleration of drying.



JULY, 1964

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ACCELERATING THE DRYING OF REDWOOD LUMBER[1]

ACCELERATION in the kiln drying of redwood can be accomplished effectively by the use of low temperatures, not to exceed 120°F, combined with a stepwise reduction in relative humidity over about two thirds of the total drying time required.

As long as the wood is above the fiber saturation point, increases in temperature above 120°F will cause collapse in a certain portion of lumber. Thus, the slowest-drying pieces should determine the drying progress.

Under the segregation procedure presently used, the shortest feasible kiln drying time for 4/4″ heavy segregation lumber appears to be 26 to 27 days. Better and faster drying can be accomplished only if lumber containing clusters of birdseye, dark birdseye, dark colored extractive streaks, and abnormal wood formation is segregated and air seasoned before kiln drying. Because of the great variation in the drying rate, moisture gradient, and thus in the stress pattern of boards during drying a better and, ultimately perhaps, automated segregration is desirable.

An even greater saving in air seasoning as well as kiln-drying time results from a presteaming treatment. However, in order to prevent checking of birdseye, lumber containing this feature has to be segregated.

An increase in the air speed normally used in commercially available kilns (around 400 to 500 ft per minute) does not aid appreciably in decreasing the over-all drying time because the drying rate largely depends on the water and water vapor diffusion through wood below the fiber saturation point.

Kiln drying redwood green from the saw does not eliminate sticker stain. A more intensive study would have to verify the impression that staining is generally reduced by this drying method.

A plot of drying rate against the current moisture content of boards on a log-log scale yields a straight line. This relationship can be used to estimate drying time from previously taken records and is accurate mainly during the second drying stage after capillary water movement has come to a halt.

Kiln drying heavy segregation lumber green from the saw is very costly. However, since temperatures should not exceed 120°F for about two thirds of the total drying time, "predriers" or low-temperature kilns could be used in combination with conventional dry kilns. This combination may compare favorably with the present procedure of air seasoning followed by kiln drying, and bring the market closer to the saw.

LITERATURE

AS EARLY as 1925, a comprehensive study was published (Green, 1925) which reported on the problems of air seasoning and commented on piling methods, sticker spacing, yard layout, and lumber segregation, and also gave information on proper kiln construction. The immediate objective of this study was to find a profitable balance between drying time required and losses occurring from degrade of the stock due to drying defects.

The large number of investigations since that time was more or less focussed on this basic objective.

An increase in the drying rate of lumber stacked for air seasoning by proper yard layout and the prevention of end checking were of main interest (Anon., 1935). The principal questions to be answered in kiln drying were originally connected with the drying

[1] Submitted for publication December 16, 1963.

behavior of the wood, the wide variation encountered in the drying rate of boards as related to visible characteristics, and the construction and use of kilns and kiln equipment. (Rankin, 1929; Utschig, 1935; Stegeman, 1938 and 1943; Davis, 1943*b*). In kiln drying redwood lumber, the main concern was with two defects, collapse and checking of birdseye, although the occurrence of stain was also undesirable (Davis, 1943*a*). Of course, other defects like checking and warping would develop whenever improper drying methods were used or abnormal wood formations were encountered. In general, such degrade was not frequent. Kiln operators always encountered losses due to collapse which seemed to range between 2 and 10 per cent of the total amount of lumber being dried. Air seasoning followed by kiln drying reduced, but hardly eliminated, the occurrence of collapse. Checking or "popping" of birdseye was believed to be caused by the more rapid drying of birdseye than of surrounding wood. A birdseye is actually an adventitious branch bud and behaves similar to a knot upon drying. Two types of birdseye could be differentiated—light and dark. It is found singly, in groups of a few, or in big clusters. Checking occurred more frequently in dark birdseye.

To segregate redwood lumber in classes having approximately the same drying characteristics, Stegeman (1940) recommended first sorting of the mill-run product into three weight classes according to moisture content. Stegeman later pointed out that a great difference in the drying rate existed between lumber having coarse grain and lumber with dense grain and a high percentage of summerwood.

To compare experimental results and exchange personal experiences in the drying of redwood at different mills, the Redwood Seasoning Committee of the California Redwood Association was formed and a continuing series of minutes of meetings and discussions was published and new research initiated (Calif. Redwood Ass'n, 1944). A series of publications produced after the war gave specific recommendations for economical and high-quality air and kiln drying of redwood lumber (Manson and Clayton, 1948; Manson, 1949). It was again suggested that green lumber be sorted into three weight segregations in case the lumber is to be thoroughly pre-air seasoned. When the largest portion of the lumber was to be kiln dried green from the saw, a fourth segregation including all boards containing massed or black birdseye, water streaks or streaks of yellowish or brown color, bands of compression wood or abnormal grain formation or of extremely fine grain was recommended. Under all circumstances this fourth segregation was to be air dried before being brought to the kilns. Generally for all redwood lumber, air drying before kiln drying rendered the best results as far as the quality of the lumber was concerned. Finally, kiln schedules for pre-air seasoned as well as for green lumber were derived which safeguarded against great losses from defects.

An attempt to market the lumber closer to the saw was made by using predriers to bring the lumber down to the fiber saturation point in a much shorter time than could be done by air seasoning (Sherman, 1937; Clausen, 1953; Anon., 1955). The advantages of a predrier were the following: 1) a constant, planned production of partially dried lumber, 2) a reduction in the volume of inventory, 3) a reduction in losses from end checking and a decrease in the occurrence of sticker stain. Also a fan-drying system was designed to reduce the shipping weight of redwood 2×4 studs (Tarason, 1957).

Following the very extensive California Redwood Association reports, mentioned before, quality-control studies were undertaken making use of statistical techniques in order to assure either uniform final moisture contents of the end product or to develop time schedules for kiln dry-

ing of pre-air seasoned stock (Manson, 1950; Pratt, 1953*a;* Lane *et al.*, 1956; Johnson, 1958).

Again the increase in the drying rate of lumber in the air seasoning yard and the prevention of end checking became the two major areas of investigation. The performance of end sealers was studied (Clausen, 1953*a;* Lambert and Pratt, 1955; Dost, 1956*b;* Brubaker, 1959). An increase in the drying rate of lumber was found possible by proper spacing between lumber piles. For this reason, the effect of pile spacing on the drying rate and the cost of air seasoning were investigated (Pratt, 1951; Clausen, 1953*b;* Dost, 1956*a*). Increased drying rates of units in air seasoning yards and a reduction in stain usually occurring in lumber were attained by the use of cover roofs (Benjamin, 1962).

The presence and distribution of extractives in redwood had been studied (Shearrard and Kurth, 1933) and groundwork for the recognition of the chemical nature of these extractives was laid (Buchanan *et al.*, 1944; Anon., 1945). The distribution pattern of these extraneous materials within boards was investigated in green, air dried, kiln dried and solvent seasoned lumber (Pratt, 1953*b;* Anderson *et al.*, 1960; Anderson and Fearing, 1961). Research results suggested that chemical stain is associated with the movement of water which carries water-soluble extractives to the surface of the lumber. The process underlying the discoloration of redwood was also investigated by determining various physical and chemical factors on which the darkening of the aqueous extract of redwood depended (Zavarin and Smith, 1962). Finally, a new phenolic compound responsible for the discoloration was isolated (Balogh and Anderson, 1964).

Many attempts were made to prevent the development of stain in redwood lumber. Treatments with various aqueous solutions of chemicals had a negligible effect (Johnson, 1956). Some believed that drying lumber immediately after it is sawn reduces the occurrence of stain to a large degree (Manson, 1949). On the other hand, the results of laboratory investigations seemed to indicate in one case that variations in the drying methods or drying schedules will not provide means of controlling stain (Ellwood *et al.*, 1960). In another case, air drying followed by kiln drying resulted in less stain than kiln drying from the green condition (Ellwood and Erickson, 1962). Presteaming of redwood lumber at 212°F before drying proved to be successful in reducing, to a certain degree, the development of stain and extractive bleeding (Ellwood *et al.*, 1960; Ellwood and Erickson, 1962; Benjamin and Tobey, 1961; Ecklund *et al.*, 1962).

The problem of accelerating the drying of redwood had once been approached by using various chemical dip treatments before conventional drying; however, this method did not appear very promising.[2] Again in recent years, the interest in accelerating lumber drying had led to a number of experimental studies.

Solvent seasoning, using acetone as an extractant, proved in pilot test runs to be a rapid method of removing water and some extractives from redwood, thus minimizing stain in the dried material and yielding the extractive as chemical by-product (Anderson and Fearing. 1961; Anderson *et al.*, 1962).

The presteaming treatment was also used successfully to increase the drying rate of lumber in air and kiln drying (Ellwood *et al.*, 1960; Ellwood and Erickson, 1962; Benjamin and Tobey, 1961; Ecklund *et al.*, 1962). The reduction in drying time was explained partly by direct expulsion of water, rapid vaporization of moisture during the cooling period after steaming and presumably an increase in the permeability of wood (Ellwood and Ecklund, 1961).

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[2] Espenas, L. D. Accelerated drying of 3-inch redwood. Unpublished report, USDA, Forest Prod. Lab.

PRESENT PRACTICE

TODAY THE DRYING practice of all large redwood mills with dry kilns is to segregate first the green redwood lumber on the basis of drying requirements or characteristics—which are recognized by weight and appearance. Usually the lumber is segregated into light and heavy classes. However, some mills practice three-way segregation including a medium-weight class. The light segregation is kiln dried from their green condition to the desired moisture content in a comparatively short time. Heavy (and usually medium) segregation lumber, however, is first air seasoned to between 30 and 50 per cent moisture content before being kiln dried. A survey showed that the amount of lumber first air dried and then kiln dried represents between 51 and 75 per cent of a mills production. The air drying period extends over 6 to 12 months depending on the local climate, the policy of the mill, and the current market situation. Kiln drying that follows air seasoning requires an additional 6 to 20 days. The wide range in kiln drying time is explained by the range in moisture content of the lumber going into the kilns and by the fact that almost every mill uses a different kiln schedule.

Air drying followed by kiln drying has the advantage that most of the free water in the wood is evaporated during the air-seasoning period and the kiln capacity required is kept to a minimum. Drying defects are largely prevented. On the other hand, a large air-drying yard and a high capital investment in stored lumber is required. Even mills with a large inventory cannot always be in the position to fill an order immediately. From all the other methods of drying mentioned in the literature, only predrying is used to a very limited degree. Kiln drying heavy segregation lumber from its green condition is very seldom practiced and the schedules suggested for it (Manson, 1960; Rasmussen, 1961) are almost never used because 30 to 35 days are required to dry 4/4″ green stock to about 10 per cent moisture content.

EXPERIMENTAL OBJECTIVES

THE EXPERIMENTAL OBJECTIVES of this study were to establish to what degree and by which conventional means the kiln drying of heavy segregation redwood lumber can be accelerated without diminishing product quality; and to investigate the influence of the three parameters of drying—air temperature, relative humidity, and air velocity, as well as the effect of presteaming.

MATERIAL AND EQUIPMENT

"CLEAR ALL HEART" and "A" grade lumber was broken down into two main groups with three subgroups. The two main groups were flatsawn and quartersawn boards. The subgrouping was accomplished by segregating into: 1) lumber exhibiting a large number of birdseye, single and/or in clusters, but free of water streaks; 2) lumber having a large amount of water streaks but virtually no birdseye; and 3) lumber free of characteristics mentioned in 1) and 2). Experimental drying of lumber segregated in this way made it possible to note under which drying conditions and at what particular stage of drying the different drying defects may occur.

To assure that only green material was used, the boards were cut from freshly sawed logs, segregated by category on the green chain, and wrapped and shipped to the University Forest Products Laboratory at Richmond as quickly as possible. The material was received in small batches with delivery coinciding with kiln scheduling. The boards used for the first kiln runs were received as 4/4″ lumber. The major portion of boards, however, was shipped as 8/4″ lumber

and resawn at the Laboratory. In this way matched material was obtained and water streaks could be marked on the freshly sawn surface.

For the preliminary study, the kiln charges were constructed as follows: Experimental kilns with variable air velocities were baffled extensively and 10 boards (1″ × 6″ × 8′) were dried in each test run. In addition a microkiln was constructed in which intensive studies on still smaller quantities (10 samples 22″ in length) were dried.

After establishing a knowledge of drying rates and occurrence of defects under various conditions, three kiln runs were conducted using mill-run heavy segregation lumber. One kiln run was carried out on 100 M bd ft in the kilns of the Union Lumber Company in Fort Bragg by the company personnel, one on about 2 M bd ft in an experimental kiln of the Pacific Lumber Company, and the third on 5M bd ft in a kiln at the University Forest Products Laboratory.

PROCEDURE

Air velocity and drying behavior

As a first step the influence of various constant drying conditions on the occurrence of defects in boards was investigated (table 1). In addition, 2 ft long, end-coated samples were dried in conditioning rooms with constant climate. They were end matched with a number of boards dried in some kiln runs.

A duplication of certain kiln runs were made with only the air velocity changed. Air speeds of 380 and 980 ft per minute were chosen. It was also investigated whether a difference existed in the drying rate of closely matched 22″ sample boards dried at 110°F with a 20°F wet bulb depression and air velocities of 214 and 107 ft per minute.

The current moisture content for each individual board was calculated on the basis of oven dry weight from weight recordings made once and sometimes twice a day in connection with the visual

Table 1. DRYING CONDITIONS FOR PRELIMINARY INVESTIGATIONS OF DRYING CHARACTERISTICS AND THE INFLUENCE OF AIR VELOCITY

Temperature °F		Air velocity ft/min	Kiln run number	Lumber characteristic	Grain direction	Selection of material
Dry bulb	Wet bulb					
150	110	380	3	plain	flat and vertical	randomly
150	110	980	4	plain	flat and vertical	randomly
130	95	380	5	waterstreak	flat and vertical	matched by resawing
130	95	980	6	waterstreak	flat and vertical	matched by resawing
130	95	380	7	birdseye	flat and vertical	matched with kiln run 8
120	90	380	1	waterstreak and birdseye	flat	randomly
120	90	380	2	waterstreak	vertical	randomly
110	90	380	8	birdseye	flat and vertical	matched with kiln run 7
73	55	5	conditioning rooms	waterstreak and birdseye	flat	end matched with boards in kiln run 1
70	62	5	conditioning rooms	waterstreak and birdseye	flat	end matched with boards in kiln run 1

inspection for drying defects. The relationship between drying rate and moisture concentration in lumber was analyzed statistically by a regression analysis using the method of least squares.

The steepness of moisture gradients established in green boards when dried under relatively mild kiln conditions was determined to show approximately when the evaporation of free water from the surface was ended and the evaporation zone had moved into the interior of boards. Also observations were made whether interior checking of birdseye would occur. This was accomplished by periodically cutting samples from all boards in two kiln runs. They were cut into 5 thin slices about ⅕″ thick. The slices were closely inspected and their moisture content determined.

Relative humidity

Gradual lowering of the relative humidity early in a kiln run was investigated as one of the means to increase the drying rate. Such a procedure, although suggested by the U. S. Forest Products Laboratory (Rasmussen, 1961), is not followed in any one of the commercial schedules. The first kiln run [KR 13] was a modified version of the US FPL schedule (table 2). The only change was an initial lower wet-bulb depression, which seemed to be justified by results of previous tests. The other two runs [KR 13A and 14] introduced further modifications in temperature during the intermediate stages of drying. The material in all three runs consisted of lumber selected to contain birdseye and waterstreaks. The air velocity was 380 ft per minute for all runs.

Presteaming

Presteaming of lumber was included in this study. Two- and four-hour steaming periods were employed. Presteamed boards and controls were always matched. In the first test, six 2″ × 6″ × 8′ bastard-sawn boards containing a large amount of birdseye in clusters were resawn and surfaced green. Half the number of resulting 4/4″ boards were presteamed for two hours at 212°F. After removal from the steam chamber they were allowed to cool for half an hour after which all the boards were dried in the same charge under equal conditions.

The second test was carried out on 22″ long samples which were dried together

Table 2. EXPERIMENTAL KILN RUNS WITH DECREASING WET BULB TEMPERATURES DURING THE EARLY STAGES OF DRYING

Moisture content	KR 13		KR 13A		KR 14	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
Per cent	Temperature °F		Temperature °F		Temperature °F	
Initial – 2 days	110	95	110	95	110	95
– 90	110	90	110	90	110	90
90 – 70	110	90	110	90	110	85
70 – 60	110	90	110	90	110	80
60 – 50	110	90	110	85	115	85
50 – 40	110	85	110	80	120	88
40 – 30	110	80	120	88	120	85
30 – 25	120	85	120	85	125	90
25 – 20	130	95	125	90	130	95
20 – 15	140	105	130	95	150	115
15 – end	180	130	150	115	170	135
Equalizing	180	152	170	150	170	150
Conditioning	180	170	180	170	180	170

with matched controls in the microkiln. In this instance, the presteaming period lasted for four hours with one hour cooling. The control set was started drying while one half of the samples underwent the steaming treatment.

Extractive concentration

The influence of presteaming and rapid drying on the extractive concentration in the surface layers of boards was investigated.

In the first test, the concentration of water soluble extractives was determined on matched 1″ × 6″ × 22″ samples boards in the 2 mm surface layer and in the 2 mm layer taken from the very center of the boards. The amount of extractives was determined, when the wood was green after kiln drying, from the green condition, and after presteaming followed by kiln drying. Extraction was done with hot water for 24 hours in a Soxhlet extractor.

A second test was carried out on another board in almost the same manner as described above. However, only the extractive content in the surface layer was determined. The remaining samples now surfaced were placed in a conditioning room and exposed to high relative humidity (70°F and 95 per cent RH) for a four-month period. This exposure is a proven method to accelerate or initiate staining.

Average mill-run lumber

Also investigated was the effect of drying on the behavior of average mill-run heavy segregation lumber grown in different areas of the redwood region.

First, a kiln charge consisting of approximately 100 M bd ft 4/4″ lumber was dried by the Union Lumber Company at Fort Bragg, using a schedule quite similar to the one used in kiln run 14. Drying time was equally divided between a predrier and a conventional kiln. The progress of drying was observed on 30 kiln samples. After completion of drying, the rough lumber was inspected on the dry sorter by kiln personnel and company graders.

The schedule used in kiln run 13A was evaluated on mill-run lumber dried at the Pacific Lumber Company, Scotia. One unit of 208 4/4″ boards ranging from 14 to 20 ft in length was dried in the small experimental kiln of the company. The progress of drying was followed by using 10 kiln samples which had been selected for their original heavy weight and density. After drying, each board was inspected for drying defects by a company grader.

A final kiln run was carried out on 5 M bd ft of 4/4″ lumber which had been cut at the Samoa mill of Georgia Pacific Corporation. The charge was dried in a kiln of the Richmond Laboratory. Boards in only two out of four units were end coated on one side to make possible a comparison whether end coating would prevent checking. The air velocity through the courses averaged 295 ft per minute. The kiln conditions were changed according to the average moisture content of ten samples, which were prepared from heavy and dense boards, and the schedule used in kiln run 13A. In addition, the amount of strain developed and the moisture content at different depths at each stage of drying were determined on two 6″ wide, flatsawn boards with growth rings of wide curvature. Observations were made on wafers cut from the boards 1 inch along the grain. Each wafer was cut into five strips 4 mm thick, with strips 1 and 5 taken from the surface, strips 2 and 4 from the intermediate zone, and strip 3 representing the center zone. The strain pattern was determined by measuring the change in width of each strip before and after sawing it from the wafer (McMillan, 1958). After completion of the kiln run, all boards were inspected by graders of the Redwood Inspection Bureau before and after remanufacturing them to S4S boards and bevel siding.

RESULTS AND DISCUSSION

Air velocity

The increase in air velocity from 380 to 980 ft per minute had a relatively minor effect on the over-all drying rate (figures 1 and 2). A comparison of the drying rates of matched boards in kiln runs 5 and 6 showed that faster drying was accomplished only during the very first portion of drying (table 3). After that, the moisture concentration in the wood appeared to be the main factor in determining the drying rate. A similar re-

Figure 1.

INFLUENCE OF AIR VELOCITY ON DRYING TIME

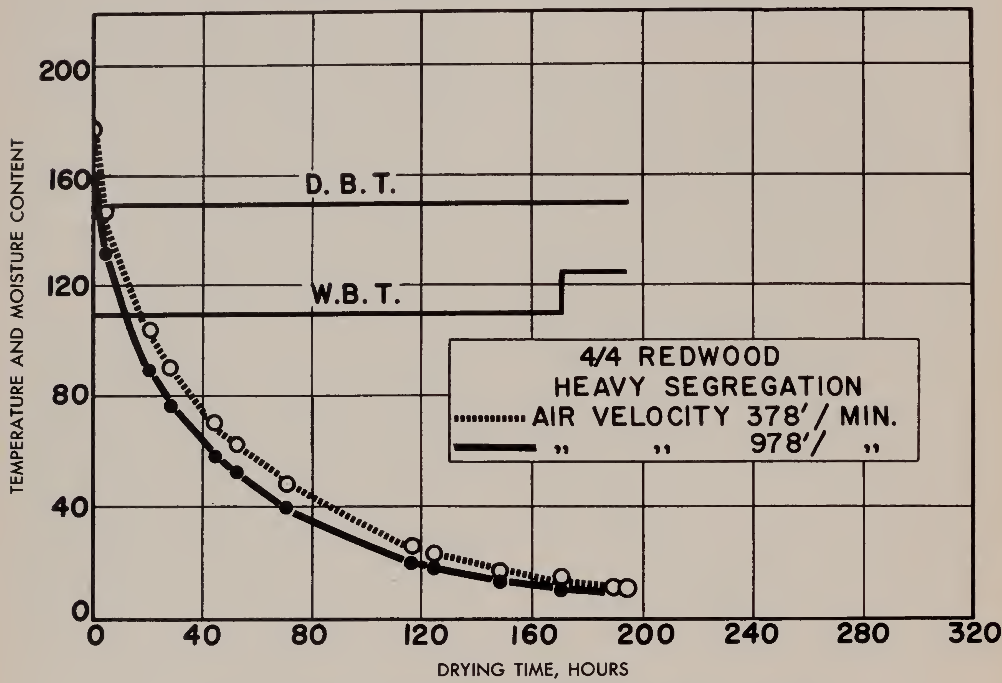


Table 3. DRYING OF HEAVY-SEGREGATION 4x4" REDWOOD LUMBER AT TWO DIFFERENT AIR VELOCITIES

Conditions: 130° F dry bulb temperature
95° F wet bulb temperature

Air Velocities: KR 5:380 ft/min
KR 6:980 ft/min

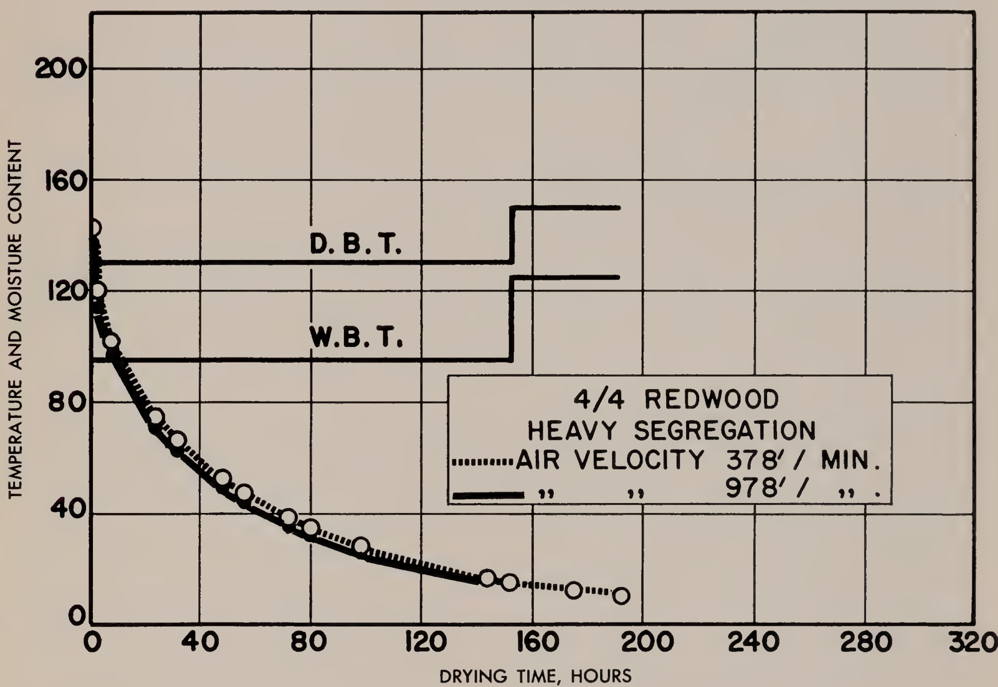
Drying time	Average moisture content [per cent of oven-dry weight]		Average drying rate [per cent moisture content per hour]	
hours	KR 5	KR 6	KR 5	KR 6
0	141	138	6.867	7.933
3	120.4	114.2	3.640	3.360
8	102.2	97.4	1.700	1.650
24	75.0	71.0	1.025	1.013
32	66.8	62.9	0.863	0.825
48	53.0	49.7	0.675	0.675
56	47.6	44.3	0.563	0.537
72	38.6	35.7	0.450	0.400
80	35.0	32.5	0.355	0.350
98	28.6	26.2	0.256	0.226
144	16.8	15.8	0.175	0.175
152	15.4	14.4		

Table 4. SLOPES OF REGRESSION LINES CALCULATED FOR THREE SETS OF DATA

Drying conditions			Number of		Avg. initial M.C.	Regression-line			
DBT	WBT	Air veloc.	Boards	Observa-tions		Regr. coeff. n-slope	Drying rate at 100% MC % MC loss		Correlation coeff.
°F	°F	ft/min			Per cent		per hr	per day	
150	110	380	10	100	180	1.271	2.01	48.2	.961
130	95	380	10	110	142	1.360	2.18	52.3	.916
110	90	380	10	104	115	1.544	1.22	29.3	.895

Figure 2.

INFLUENCE OF AIR VELOCITY ON DRYING TIME



sult was obtained by observing the drying rate of end- and side-matched 22″ long sample boards dried in a microkiln at air speeds of 214 and 107 ft per minute.

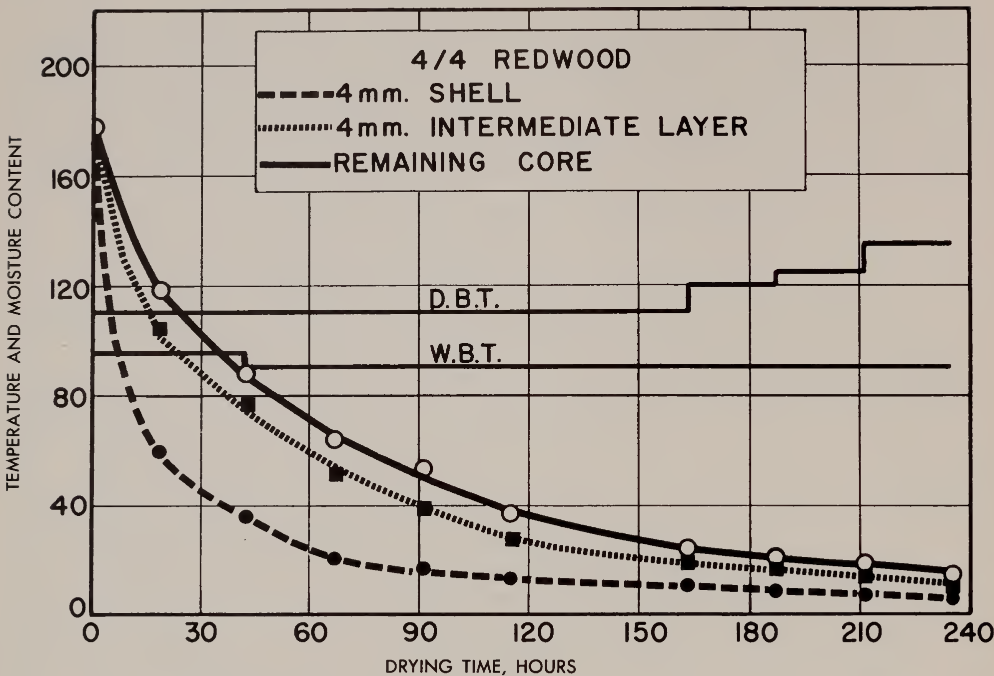
The explanation for these results lies in the fact that the surface of redwood lumber dries rapidly and the capillary moisture movement to the surface comes to an early halt (figure 3). Once the surface layers are depleted of free water, the moisture has to move through them by diffusion.

Although higher air velocities had little influence on the over-all drying time, it should not be concluded in the commercial kiln drying practice for redwood that an extremely slow air circulation would be just as effective as the generally recommended higher velocities.

For good uniformity in drying throughout the kiln, a fairly high air velocity is usually necessary to prevent too great a temperature drop and humidification of the air moving across the load. (Most of the double track redwood kilns having an air speed of 350 ft per minute and more on the leaving side of a charge seem to perform satisfactorily). If higher

Figure 3.

MOISTURE DISTRIBUTION AT DIFFERENT DEPTHS



air velocities are contemplated, the economic aspect of power consumption will have to be considered. The energy required to turn fans varies with the 2.4 to 3.0 power of the increase in air speed (Kollmann and Schneider, 1960).

Drying rate

The dependency of drying rate on the current moisture content of the wood was quite apparent under constant drying conditions. A straight-line relationship between the logarithmic transformation of their values could be used to estimate the progress of drying quite closely (correlation coefficients of 0.9 and above). In other words, when the moisture content loss per unit time was plotted against the average moisture content on log-log paper, a straight line relationship was obtained.

This result is in close agreement with findings by Peck *et al.* (1952). They started with the general diffusion equation for one-directional diffusion of moisture through sides of a rectangular slab and developed the following drying rate equation:

$$\frac{d\bar{C}}{d\theta} = -M\bar{C}^n$$

where $d\bar{C}$ = change in average moisture
$d\theta$ = change in time
$\bar{C}$ = average moisture content

The exponent n is equal to the slope of this line. The value M, read on the ordinate, is equal to the drying rate $\frac{d\bar{C}}{d\theta}$ at the average moisture content $\bar{C} = 1$. The time required for the drying of a board from one given moisture content to another can be calculated by integration of this rate equation.

The slopes of regression lines calculated for three sets of data obtained in this study are presented in table 4.

In respect to the method of evaluating drying rates demonstrated here, the fol-

lowing must be considered. The sample size was relatively small, and the results may not be representative of all heavy segregation redwood lumber. However, they were quite useful for this study. The method has the limitation that the initial moisture content of boards will influence the regression line to a certain extent. Thus the above formula does not describe the initial stage of drying during which free water is brought to the surface by capillary action and evaporated there. Further, one has to keep in mind that the regression lines are based on drying rates observed on boards dried in an experimental kiln. They will not apply to a commercial kiln where cooling and humidification of the air takes place while it moves across the load. Therefore, drying rates in commercial kilns are much slower.

Temperature

Using higher temperatures to accelerate drying is not advisable for the first and second stage of drying because collapse is likely to occur.

During the first portion of the study, when the development of defects was observed under constant and changing kiln conditions (kiln runs 1 through 14), collapse appeared closely related to temperature and the moisture content of the lumber. The higher the temperature to which the lumber with a moisture content above the fiber saturation point was subjected, the larger was the amount of collapse. Lumber without birdseye had a critical temperature of approximately 130°F. Above this temperature collapse occurred more frequently. Lumber with a large amount of birdseye, especially when present in clusters, and lumber containing dark streaks indicating a high extractive content, showed areas of collapse at lower temperatures. The critical limit appeared to be around 120°F. It was not noticed that collapse occurred more frequently in areas of waterstreak than in the adjacent wood.

Under constant drying conditions, the presence of collapsed cell formation usually became noticeable when the lumber contained from 30 to 80 per cent moisture. When the kiln conditions were changed stepwise (kiln runs 13, 13A, and 14), collapse did not occur until the temperature was raised to 130°F and higher. Then, a few sample boards in either run showed slight depressions which always surfaced off when the lumber was planed to 25/32 of an inch. It was interesting that at the time these slightly collapsed areas became noticeable, the average moisture content of such boards was between 35 and 20 per cent. Because of the fairly steep moisture gradiant, however, the core of these boards still contained up to 50 per cent moisture content.

Toward the end of the kiln runs, when higher temperatures could be used safely, it was not possible to shorten the drying time. Because of the ununiformity in drying rates between heavy segregation boards, some of them reached a moisture that commanded the start of an equalizing treatment while others had moisture contents around the fiber saturation point.

Relative humidity

Gradual lowering of the wet-bulb depression at constant low dry-bulb temperatures increased the drying rate appreciably during the second stage of drying. The drying time for kiln runs 13, 13A, and 14 were respectively 9, 11 and 15 per cent shorter than the drying time required to bring lumber from an initial average moisture content of 165 per cent to 40 per cent under a constant kiln setting of 110°F with a 20°F wet-bulb depression.

Birdseye proved to be quite sensitive to high temperatures and/or low humidities. This was true mainly during the first days of drying when the surface layer of heavy segregation material dried down very rapidly. The checking of light birdseye could always be prevented by using a starting temperature of 110°F with a

Table 6. KILN RUN AT UNION LUMBER COMPANY

Day	DBT	WBT	Average M. C.	Average M. C. loss per day	Day	DBT	WBT	Average M. C.	Average M. C. loss per day
	°F	°F	per cent	per cent		°F	°F	per cent	per cent
0	110	90	177.3	....	14	120	90	...	...
1	110	90	152.0	25.3	15	120	90	29.6	4.6
2	110	90	.....	....	16	125	90	...	...
3	110	90	113.6	19.2	17	125	89	...	..
4	110	90	.....	....	18	130	95	...	...
5	110	87	91.1	11.3	19	135	100	...	...
6	110	84	.....	....	20	140	105	15.5	2.8
7	110	81	.....	....	21	145	110	...	...
8	112	83	.....	....	22	150	115	...	...
9	115	86	.....	....	23	155	120	...	...
10	118	86	52.7	7.7	24	160	120	9.3	1.6
11	120	87	.....	....	25	170	120	...	...
12	120	88	.....	....	26	160	135	6.7	1.3
13	120	88	.....	....	27	170	160	8.6	...

juice was pressed out of closely matched green redwood samples of which half had been steamed at 212°F for four hours, a colorimetric comparison in alkaline medium showed no difference between the sampled liquid.[3]

Kiln runs on mill-run lumber

In the first commercial kiln run at Union Lumber Company the time required to reduce the average moisture content of the kiln samples from 177.3 per cent to 6.7 per cent was 26 days. During one additional day, the lumber was conditioned and the moisture content of samples raised to 8.6 per cent (table 6). The time required to complete this kiln run was much longer than for the experimental drying in the laboratory kiln. Again, this is explained by the temperature drop and humidification of air which takes place across two 8 ft-wide loads in a double track predrier or kiln. From the seventh day on the lowest obtainable wet-bulb depressions were used.

The inspection of the lumber on the dry sorter showed that the number of boards in the entire charge which showed seasoning defects amounted to less than 4 per cent. The defect most often encountered was collapse. All of the boards with collapse were of dark color indicating a high extractive content. The amount of degrade was not exceptional, and the kiln run was considered successful.

The progress of drying in the experimental kiln of the Pacific Lumber Company is diagrammed in figure 5. The original average moisture content of 167.5 per cent in the 10 samples was reduced to 7.0 per cent in 22 days. At the completion of the kiln run, a "shell and core" test showed in a few samples still some casehardening, indicating the need for additional equalizing and conditioning treatment.

The main defect encountered was end checking of 20 ft long boards which had their ends overhanging while drying. It was felt that box piling of the lumber would have prevented this defect. Four per cent of the boards showed areas of collapse and 1 per cent surface checks. The general feeling of the grader was that the unit appeared similar to the normal mill run as far as drying defects were concerned.

The last kiln run carried out on stock provided by the Georgia-Pacific Corporation's mill in Samoa was concluded in 23 days. In this period, the moisture content of samples was reduced from 160.5 to 7.8 per cent (figure 6). During the first half of the kiln run, low dry-bulb temperatures

[3] Analysis by B. Balogh, Assistant Specialist, Forest Products Laboratory, Richmond.

Figure 5.

EXPERIMENTAL DRYING AT THE PACIFIC LUMBER CO.

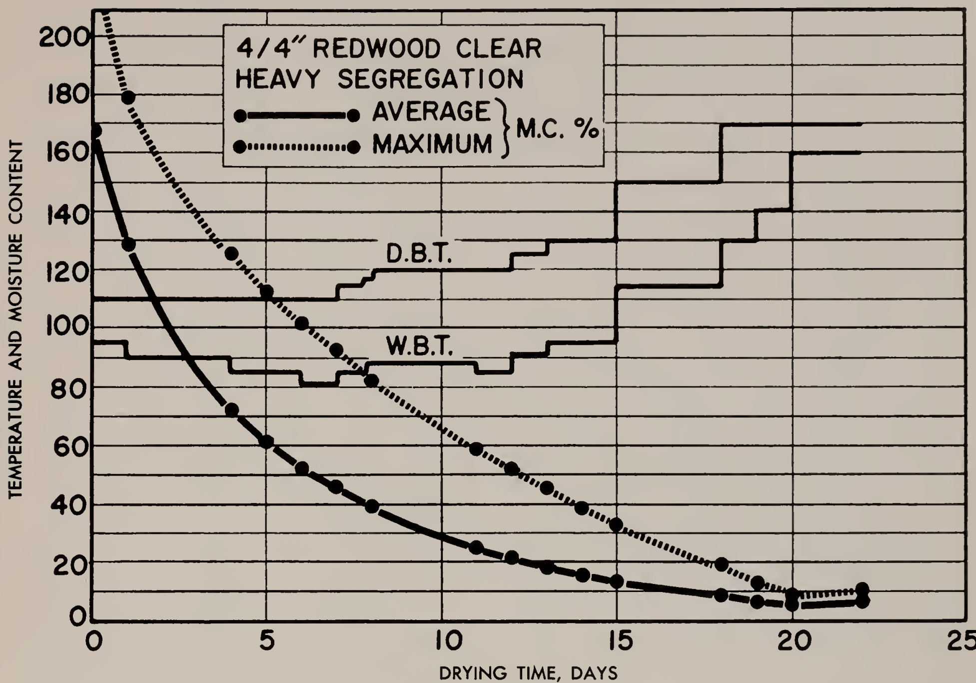
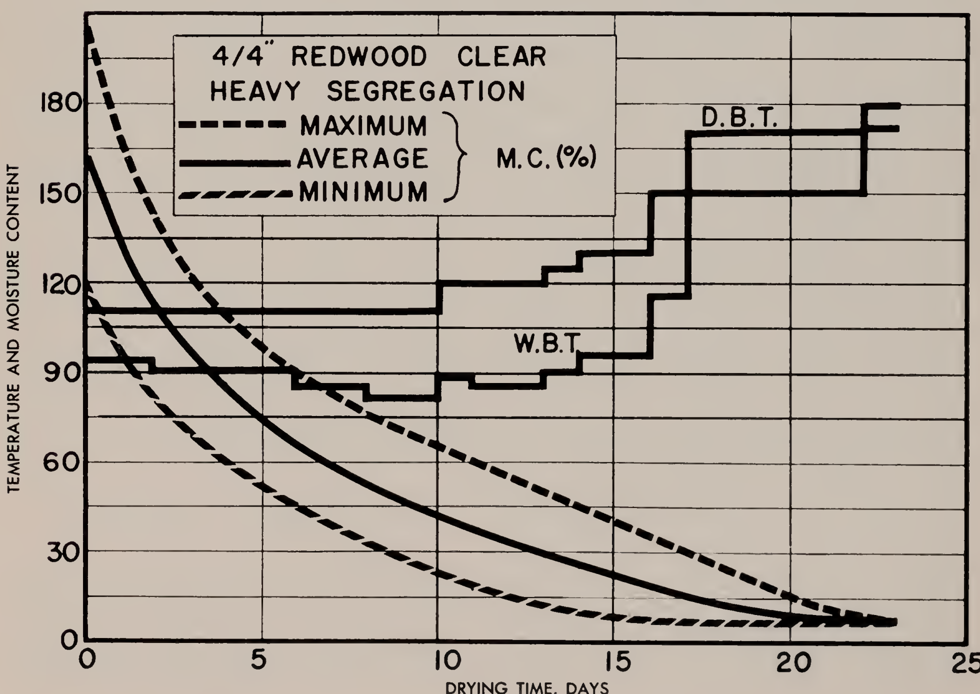


Figure 6.

EXPERIMENTAL DRYING AT RICHMOND LABORATORY



with stepwise increasing wet-bulb depressions gave good drying rates. When the average moisture content of the samples had reached 29 per cent moisture content on the 13th day, a stepwise increase in dry-bulb temperature above 120°F was started.

The kiln run, which was intended to be marginal in respect to the time-defect relationships, was only partially positive in its results. Surface and end checking was fully prevented (only one board out of the 5 M bd ft charge had a surface check and one an end check). Light birdseye was intact on the surface, and only a small percentage of the dark birdseye had fine separations. However, interior checking of birdseyes could be found and some cases of honeycomb were associated with birdseye clusters. Also about 6 to 7 per cent of the inspected boards showed areas of collapse which either had to be trimmed off or degraded the boards. The lumber generally contained more of these two defects than is usual in mill-run lumber first air seasoned and then kiln dried. It appeared somewhat brighter in color; however, some boards had sticker marks.

The moisture-content distribution and the strain patterns in the outside, intermediate, and center layer of two boards are diagrammed in figures 7 and 8. Insofar as strains are representative of stresses in boards, it can be seen that compression and tension stresses built up equally rapid in the interior and surface zones of both boards and remained at a moderate level throughout the first half of the drying time although the relative humidity was gradually reduced. Thus, checking did not occur. Stress reversal in Board 1 started quite early on the 9th day. In the second board however, stress reversal did not take place until the 16th day, yet at almost the same moisture content as in Board 1, that is, at 26 per cent. In both boards, the tensile strain reached the maximum value in the center zone shortly after stress reversal. It was believed that the interior checking of birdseye which occurred in other boards happened during such a peak period of tensile strain.

Just as the strain pattern was quite different for the two boards so was the causative moisture gradiant. All layers of Board 1 dried readily. In contrast, the intermediate layer of Board 2 reached fiber saturation point quite late on the 16th day when stresses reversed while the core was still at 54 per cent moisture content. At the same time, the kiln temperature was raised to 150°F. Although Board 2 did not collapse, others seemingly did in this stage of drying. These data, of course, are not sufficient to answer the question of whether collapse was due to either liquid tension, a result of water-filled cells at a late drying stage, or cell failure due to compressive stresses that mounted prior to stress reversal.

Looking at the entire kiln run, it appeared that the first portion of the schedule performed extremely well, but an extension of the period at 120°F would have been necessary until all boards in the charge reached fiber saturation point. From the recorded drying rates, a minimum drying time of 26 to 27 days was estimated for a commercial run that would reduce defects below an economically acceptable level. The period during which the lumber had to be dried under "low temperature drying conditions" would extend over two thirds of the total kiln-drying time.

According to information provided by personnel of the Georgia-Pacific Corporation, the schedule performs well without modification for medium segregation lumber. It is commercially used now for drying of 4/4″ lumber of this segregation from its green condition to 10 per cent moisture content in about 17 days.

ECONOMIC ASPECTS

THE SUPREME TEST of an industrial operation lies in the field of economics. Yet the separation of individual cost factors of drying often appears to be difficult in

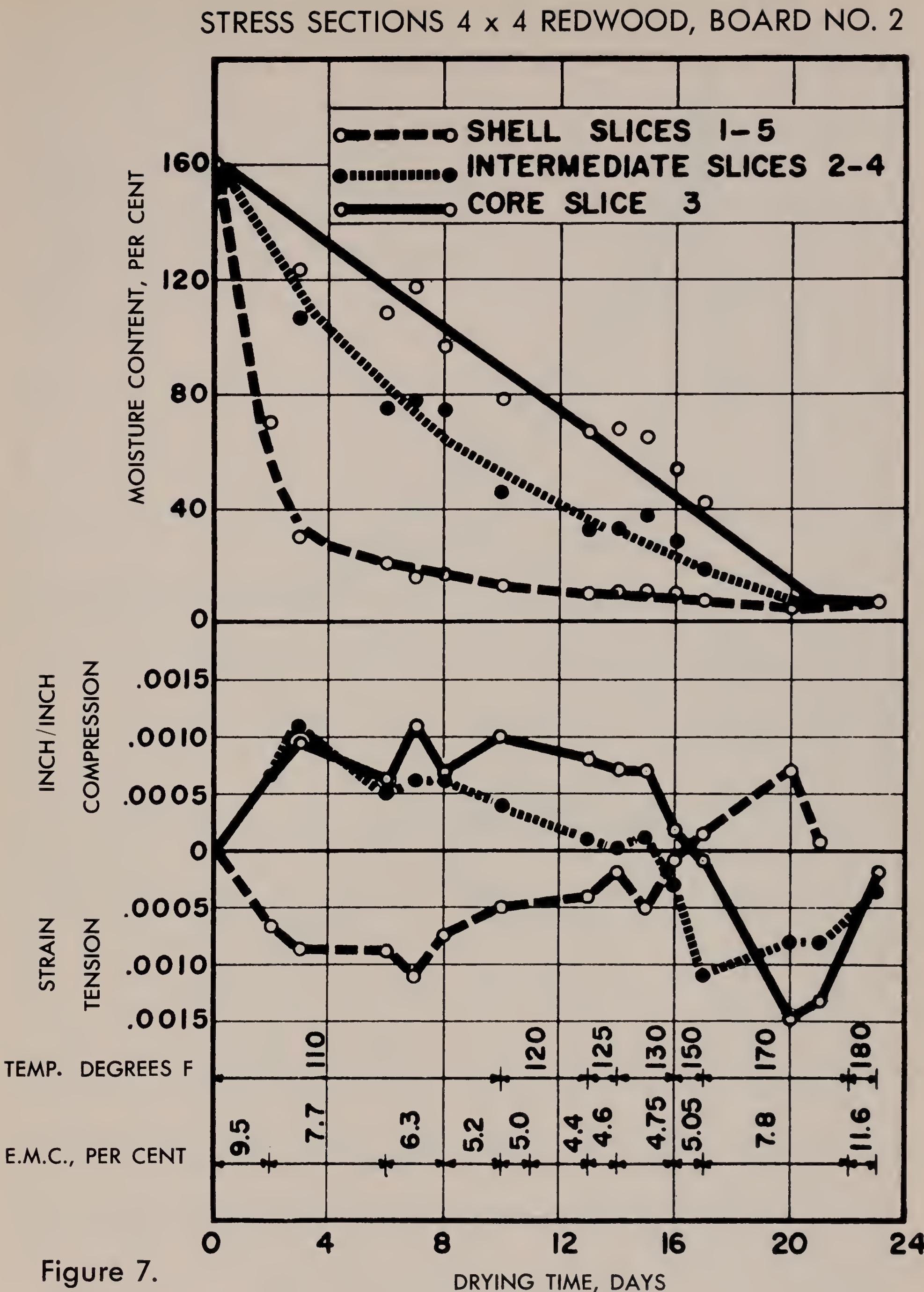


Figure 7.

an integrated lumber operation. Factors like steam and power consumption or even drying time for a given sortiment are seldom evaluated accurately. For heavy segregation lumber, the cost of drying may vary considerably from mill to mill, and it is difficult to evaluate an average for the whole industry. Different

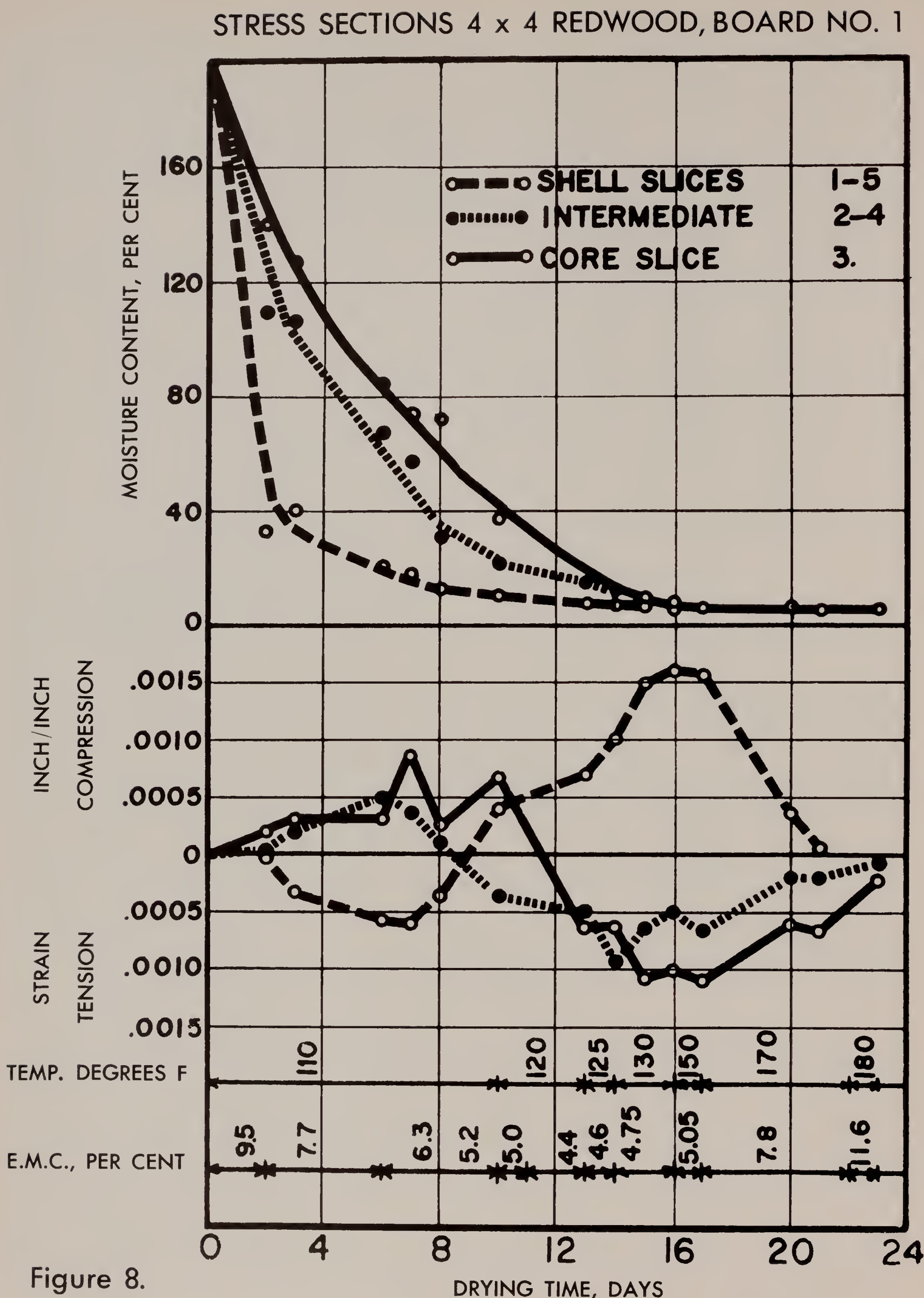


Figure 8.

operations install different types and brands of kilns, and these require different investment and maintenance expenditures. Also, different policies and drying schedules are followed. In addition, an evaluation of losses due to drying defects is hard to come by since the amount of degrade and trim varies with

Table 7. KILN DRYING COSTS USING A 100 M BD FT CAPACITY KILN

	Per year	Per day
Indirect costs		
Amortization of the kiln (over 20 years at 6 per cent interest)	$8,718.00	$23.89
Taxes (6 per cent of 1/3 of the installation cost)	2,000.00	5.48
Insurance	1,000.00	2.74
Maintenance (3 per cent of the installation cost)	3,000.00	8.22
Interest on lumber (6 per cent on $125/M bd ft)	....	2.64
Direct costs		
Electric power	3,528.00	9.67
Steam consumption	7,519.00	20.60
Labor	2,555.00	7.00
Total cost		
Dollar/day/100 M bd ft		$80.24
or		
Dollar/day/M bd ft		.80

the type of timber, drying season, kiln performance, drying schedule, and many other factors.

The total cost for drying redwood lumber was investigated when the effect of pile spacing in the air drying yard on the drying rate of lumber was determined (Pratt, 1951; Clausen, 1953*b*). Also an unpublished report[4] based on information supplied by various parts of the redwood industry compared costs of different drying methods. All these reports provide excellent information on basic cost factors, like capital investment, taxes, insurance, etc.

Our study did not intend to arrive at either a minimum or an average cost value; this would have required an exact knowledge of the monetary loss from drying defects. It was our aim to bring the experimental results into focus from an economic point of view.

In estimating kiln-drying costs, the following basic assumptions were made: the initial investment in kiln construction and kiln equipment amounts to $100,000 for a 100 M bd ft capacity kiln; the kiln operates 365 days per year. The factual amortization (not the book amortization) for such a structure is 20 years, and the value of M bd ft 4/4″ redwood lumber in the rough is $125.00. With the remaining values for insurance, taxes, and direct costs quoted from information furnished by the California Redwood Association, a cost anlaysis for kiln drying may resemble the one presented in table 7. According to the analysis of table 7 the cost of kiln drying would be $0.80 per day per M bd ft. For air seasoning, a cost of $0.03 per day per M bd ft can be quoted from the study on air seasoning by Pratt, 1951. The largest part of this later figure represents the interest on the value of lumber stored in the yard. The cost of lumber transportation for both ways, to and from the yard, may be close to $0.60 per M bd ft.

In common mill practice, the combination process of air seasoning followed by kiln drying is employed. A cost estimate for this process depends on the time requirement for the two part procedures. Here a factual drying scheme of one company may be used. It has been derived in conjunction with a quality control study of the California Redwood Association on about 90 mill bd ft and gives excellent results in respect to grade recovery. Table 8 lists the number of days required for kiln drying 4/4″ heavy segregation lumber after a given number of months of air seasoning. The scheme accounts for the seasonal differences in

[4] Dost, W. A. Seasoning costs. Manuscript at the California Redwood Association.

Table 8. TIME REQUIREMENT FOR AIR SEASONING FOLLOWED BY KILN DRYING
(based on CRA Research Report No. 3.222120)

Lumber to the yard in	Number of months in the air seasoning yard before kiln drying										
	2	3	4	5	6	7	8	9	10	11	12
	Number of days required for kiln drying										
January	27	24	22	19	16	14	12	10	7	5	
February	27	24	22	19	16	13	10	8	6	5	
March	26	23	20	18	15	13	11	9	7	5	
April	25	22	18	15	13	12	11	9	8	6	5
May	25	21	18	14	12	10	9	8	6	5	
June	25	22	18	16	14	12	10	8	6	5	
July	26	23	21	18	16	14	13	11	9	7	5
August	27	25	23	22	20	18	16	14	10	5	
September	28	27	25	24	22	19	16	13	9	5	
October	29	27	25	23	20	18	13	9	5	5	
November	30	28	26	22	19	16	12	10	5	5	
December	30	27	24	20	18	14	11	7	5	5	

weather conditions by considering the time of the year when the lumber was stacked for air seasoning.

The total cost of air seasoning followed by kiln drying can be calculated from the information on drying time presented in table 9 and the cost factors listed in table 7. Table 9 lists costs for various time combinations and from it the optimum combinations were found (minimum cost figures are underlined). The average minimum cost for the year is $14.58 per M bd ft.

Very often shorter than optimum air seasoning periods are used whenever certain assortments are needed.

From an economical point of view, the practice of kiln drying green heavy segregation lumber cannot compare with air drying followed by kiln drying, not even when an accelerated schedule requiring only 26 or 27 days is used. Kiln drying green lumber in 27 days to about 8 per cent average moisture content would cost an estimated $21.65. To come close to the cost of air drying plus kiln drying, the kiln drying time for green lumber would have to be reduced to about 18 to 22 days. This is virtually impossible. Kiln drying heavy segregation lumber directly from the saw should be practiced only when unexpected demand has to be met that justifies an extra expenditure.

The use of predriers or low-temperature kilns should be considered as a possible means of evaporating free water from lumber at a lower cost than in a kiln. For redwood predrying, temperatures up to 110°F to 120°F may be used until the lumber reaches a moisture content of 30 to 25 per cent. Below this state, optimum drying rates cannot be obtained any more, and a transfer to the kiln is necessary.

Unlike dry kilns, predriers can be made of lighter construction, do not require

Table 9. COST OF AIR SEASONING FOLLOWED BY KILN DRYING

Lumber to the yard in	Number of months in the air seasoning yard before kiln drying										
	2	3	4	5	6	7	8	9	10	11	12
	Dollars per M bd ft										
Jan.	24.08	22.58	21.90	20.40	18.92	18.22	17.54	16.84	15.42	**14.66**	
Feb.	24.08	22.58	21.90	20.40	18.92	17.42	15.94	15.24	**14.62**	14.66	
March	23.28	21.78	20.30	19.60	18.12	17.42	16.74	16.04	15.42	**14.66**	
April	22.48	20.97	18.70	17.19	16.52	16.61	16.74	16.04	16.23	**15.46**	15.59
May	22.48	20.17	18.70	16.39	15.71	15.01	15.14	15.24	**14.62**	14.66	
June	22.48	20.97	18.70	17.99	17.32	16.61	15.94	14.24	**14.62**	14.66	
July	23.28	21.78	21.10	19.60	18.92	18.22	18.35	17.64	17.03	16.26	**15.59**
Aug.	24.08	23.38	22.71	22.80	22.13	21.43	20.75	20.05	17.83	**14.66**	
Sept.	24.89	24.89	24.31	24.41	23.73	22.23	20.75	19.25	17.03	**14.66**	
Oct.	25.69	24.89	24.31	23.61	22.13	21.43	18.35	16.04	**13.82**	14.66	
Nov.	26.49	25.79	25.11	22.80	21.33	18.82	17.54	16.84	**13.82**	14.66	
Dec.	26.49	24.89	23.51	21.20	20.53	18.22	16.74	14.43	**13.82**	14.66	

steam spray lines, and can operate with a smaller coil surface area. Therefore, capital investment is less based on charge capacity.

For the theoretical cost analysis a figure of $65,000 was assumed for capital investment in a 100 M bd ft capacity predrier. Other assumptions were the following: the steam consumption of a predrier is not more than two thirds the steam consumption of a conventional kiln and the maintenance charge is 2 per cent of the installation cost. Charges for lumber transfer system could vary considerably. A figure of $0.10 per M bd ft was used in the estimation in table 10.

The estimate above gives a predrying cost of $0.575 per day per M bd ft. If a 27-day schedule is employed, with 18 days of predrying and 9 days of kiln drying, the total charge for the combination process, inclusive of transfer costs, would amount to $17.67. Accepting the accuracy of the above assumptions, it would appear that the cost for the combination process of predrying followed by kiln drying is within the economical range.

An exact cost analysis comparing the different methods of drying can only be carried out when it is based directly on a case study of a particular operation. When predrying is primarily employed, the savings due to reduced or eliminated checking and the value of marketing the lumber closer to the saw may have to be determined as well as possible losses due to other defects not encountered in air seasoning (losses due to endchecking which developed during air seasoning were found in one study (Brubaker, 1959) to range between $3.90 and $10.50 per M bd ft). The possible need for an increased dry storage area should also be considered.

Table 10. ASSUMED PREDRYING COSTS USING A 100 M BD FT CAPACITY PREDRIER

	Per year	Per day
Indirect cost		
Amortization of the predrier (over 20 years at 6 per cent interest)	$5,666.70	$15.52
Taxes (6 per cent of 1/3 of the installation)	1,300.00	3.56
Insurance	650.00	1.78
Maintenance (2 per cent of the installation cost)	1,300.00	3.56
Interest on lumber (6 per cent on $125/M bd ft	....	2.64
Direct costs		
Electric power	3,528.00	9.67
Steam consumption (2/3 of steam consumption in kiln drying)	5,013.00	13.73
Labor	2,555.00	7.00
Total cost		
Dollar/day/100 M bd ft		57.46
or		
Dollar/day/M bd ft		0.58

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ACKNOWLEDGMENTS

The authors express their appreciation for the cooperation received from the California Redwood Association whose financial support made this study possible and all of the individuals and companies concerned. Lumber was selected and supplied through the courtesy of A. F. PETERSON and D. CLAYTON of Georgia-Pacific Corporation. A trial kiln run was conducted by L. ANDREANI and D. LAZZARINI of Union Lumber Company and the other test by C. E. ASHBURN and H. BYKER, and graded by K. COVINGTON, of The Pacific Lumber Company. Further lumber inspection was carried out by R. TALVOLA, head grader, Redwood Inspection Service. Acknowledgment is also made to E. F. McINTYRE for laboratory assistance.

In order that the information in our publications may be more intelligible it is sometimes necessary to use trade names of products or equipment rather than complicated descriptive or chemical identifications. In so doing it is unavoidable in some cases that similar products which are on the market under other trade names may not be cited. No endorsement of named products is intended nor is criticism implied of similar products which are not mentioned.

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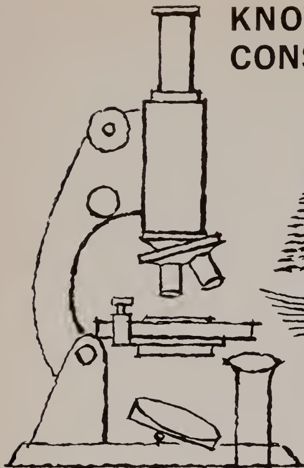
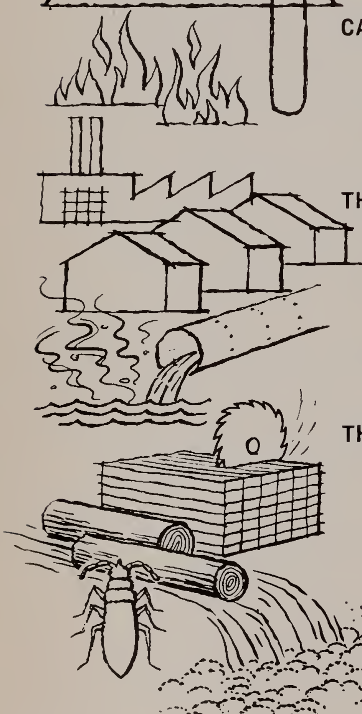
KNOWLEDGE GAINED BY RESEARCH CAN HELP CONSERVE CALIFORNIA'S WILDLAND RESOURCES





CALIFORNIA WILDLANDS...

- 65 million acres of mountains, foothills, canyons, rivers, lakes, and sea coasts.
- a giant "farm" for timber and forage.
- a vital source of California's water supply.
- an "outdoor playground" for millions of vacationers.

THE THREAT: the onslaught of...

- population growth.
- urban and industrial expansion.
- increasing demand for water, lumber, forage.
- wildfires.
- insects and plant and animal diseases.
- waste.

THE SOLUTION: coordinated research on using wildland resources to realize their full potential...

- present rate of timber growth could be doubled.
- usefulness of timber cut could be doubled by new products made from current waste.
- forage production for livestock and game could be tripled.
- watersheds could be made to yield more usable water and cause fewer floods.
- tens of millions of dollars lost to fire, insects, diseases could be saved.
- timber, forage, and recreation uses need not exclude each other.

THE WILDLAND RESEARCH CENTER at the University of California was established to help conserve California wildland resources through research. It operates within the University's state-wide Agricultural Experiment Station, with administrative headquarters on the Berkeley Campus.

THE CENTER...

- coordinates and supports research in more than a dozen fields.
- integrates studies of complex wildland problems.
- strengthens cooperation between University and other research workers.
- promotes the exchange of information between research workers and wildland managers and policy makers.
- collects and disseminates scientific data on wildland studies.

TO KNOW IS TO LIVE IN ABUNDANCE...